

# Hydrogen Maser Frequency Standard Automatic Tuning Servo

C. J. Finnie and D. A. Norris  
Communications Elements Research Section

*This article describes the microwave cavity tuner control module for the DSN prototype hydrogen maser and details its operation.*

This article describes the microwave cavity tuner control module for the DSN prototype hydrogen maser. A previous report (Ref. 1) described the general features and techniques employed in the tuning system. This report details the operation of the tuner control module.

The tuner control module (Figs. 1 and 2) can be operated in one of four modes (see front panel controls and displays, Fig. 1):

**Tune:** provides the control of hydrogen beam modulation, data acquisition, and filtering to control the tuning of the maser microwave cavity to the center of the atomic hydrogen resonance frequency (21 cm).

**Track:** allows automatic frequency tracking between the hydrogen maser and a reference oscillator with an adjustable offset.

**Hold:** allows the use of the frequency measuring techniques of the tuner system to be used as a malfunction monitor and alarm system.

**Counter:** allows the use of the tuner counters to calibrate the maser's internal test oscillator.

A block diagram of the control module is shown in Fig. 3. The *tune* mode operates as follows. The H-maser VCO is translated in frequency, by mixing it with a reference oscillator, to 0.01 Hz. The zero crossings of the 0.01-Hz beat frequency are very accurately detected and input to the tuner control module by a zero crossing detector in the H-maser receiver. These zero crossing events sequence a 3-bit binary counter, which in turn controls the following operating sequence.

The operator initializes the sequence with either the *reset* or *enter varactor* control, which sets the hydrogen flux modulation at a high flux level and the count direction of the sequence up-down counter (C1) upward. The arrival of the first zero crossing event enables C1, which counts a 1-kHz clock. The second zero event terminates the count, reverses the count direction and sets the hydrogen flux modulation to a lower level. The controller is inactive for the next period, as the physical system requires this delay to reach equilibrium. The third zero event enables a down count. If the count reaches zero before the arrival of the fourth zero event, the count

direction is reversed, and a negative error binary is set to flag the condition. The counter zero is detected by a digital comparator connected to the outputs of C1 and the front panel switch *error inhibit and alarm level*. With zero supply voltage to the comparator switch, the comparator operates as a zero detector. Because of the clocking mode of the particular counters used, the "greater than" output of the comparator is used to detect the zero count. Therefore, when the fourth zero event stops C1, the absolute value of the difference between the up count and the down count resides in C1, and the sign of the error has been stored. At this time, voltage is supplied to the comparator switch and the comparator output is used to set an "excess error" binary if the error residing in the counter exceeds the *error inhibit and alarm level* switch setting. Also at this time the value and sign of the error are strobed into the *period/period error* display. A running display of the counter operation is available at the *sequence* position of the *display* control. The latter position is primarily used for maintenance, trouble shooting, and operator orientation. After a 4-s delay, the count direction of C1 is set to down count, the comparator switch supply voltage is again set to zero, and the error is counted out of C1 at a 1-kHz clock rate. If the "excess error binary," previously described, has not been set, C2 counts a clock for the time it takes the error to count out of C1. If the error binary is set, an alarm line is set, and C2 does not count while the C1 error is being counted out. The clock rate of C2 is adjusted by the front panel control *time base*. The clock rates for C2 are 10 kHz, 1 kHz, and 100 Hz for switch positions of 0.001, 0.01 and 0.1 s, respectively. These positions correspond to module incremental gains of 0.1 V/s, 0.01 V/s, and 0.001 V/s, respectively, where time is the measured beat period error described in Ref. 1. If the period is 100 s and the oscillator reference frequency is 100 MHz, the incremental frequency error is 1 part in  $10^{12}$  per second of measured period error. This entire tuning cycle is repeated after the next zero event, except that the first count is with the flux control in the low position and the second count is with the flux in the high position. This time reversal of the measurement sequence cancels the linear term of the reference oscillator drift. The C2 error count direction is reversed to compensate for the reversal of the count time sense.

The *track* mode uses a part of the *tune* mode counting sequence. The counter C1 is operator-initialized to the setting on the *period offset* front panel switch. The flux modulation is deactivated, and the counter control binary divider is automatically preset to the count cycle condition which exists after the second zero event of the *tune* mode. The first count of the *tune* mode has therefore been replaced with a settable constant. The first zero event starts a down count; the second zero event stops the count. The error sign, comparison, alarm, and transfer features are identical to those of the tuning mode. The cycle is automatically reset after each error transfer.

In the *hold* mode the sequence counter (C1) performs as it does for the tuning mode except that the error is not transferred to the varactor counter.

In the *counter* mode the hydrogen maser internal test oscillator replaces the clock of C1, and a 1-s gate derived from division of the control unit 100-Hz clock provides a 1-Hz resolution frequency counter with a 30-kHz maximum counting rate.

The *period offset* and *reset* control provides a manual reset for all control logic and C1, leaving the count in C2 and the varactor setting unchanged. The *enter varactor* control resets all functions including the varactor counter C2. Automatic reset occurs when the position of the mode switch is changed to prevent inadvertent changes in the varactor counter (C2). The *set varactor* digital switch initializes the varactor setting in the *tune* and *track* modes and is used for manual varactor entry in the *hold* mode.

The module is built in a standard four-width nuclear instrumentation module (NIM). The logic components are transistor-transistor logic (TTL) integrated circuits. Nand gates have been used for all gating functions to reduce package types. Two identical counter printed circuit boards are used, with the comparator integrated circuits (ICs) removed for C2. Two control printed circuit (PC) boards supply the 32 gating and binary ICs for the counter control functions. The counters consist of six single-digit integrated circuits and six 4-bit comparators for the C1 counter board. A second single-width NIM houses the 16-bit varactor digital-to-analog converter.

## Reference

1. Finnie, C., "Tracking and Ground Based Navigation: Hydrogen Maser Frequency Standard Automatic Cavity Tuning Servo," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XIV, pp. 56-59, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1973.



**Fig. 1. External view of hydrogen maser cavity tuner control module**

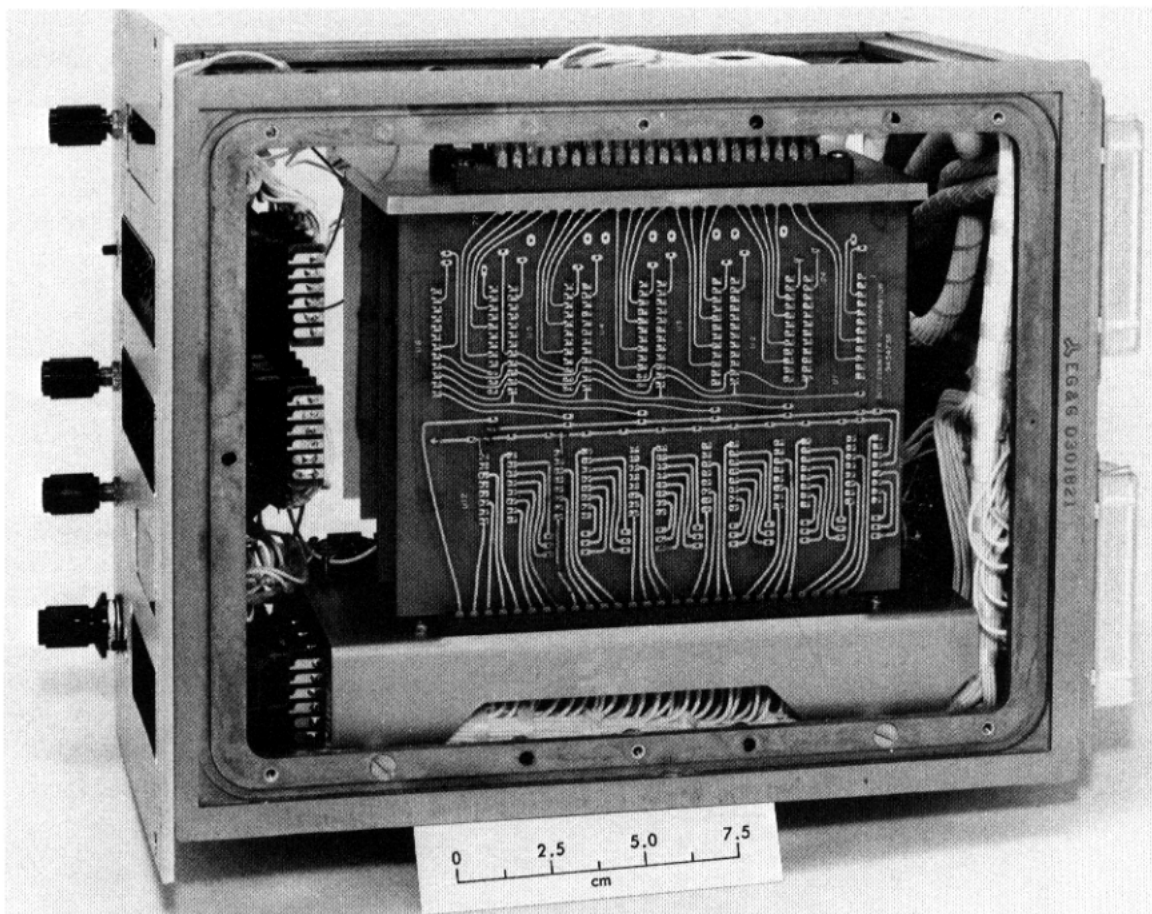


Fig. 2. Internal view of hydrogen maser cavity tuner control module

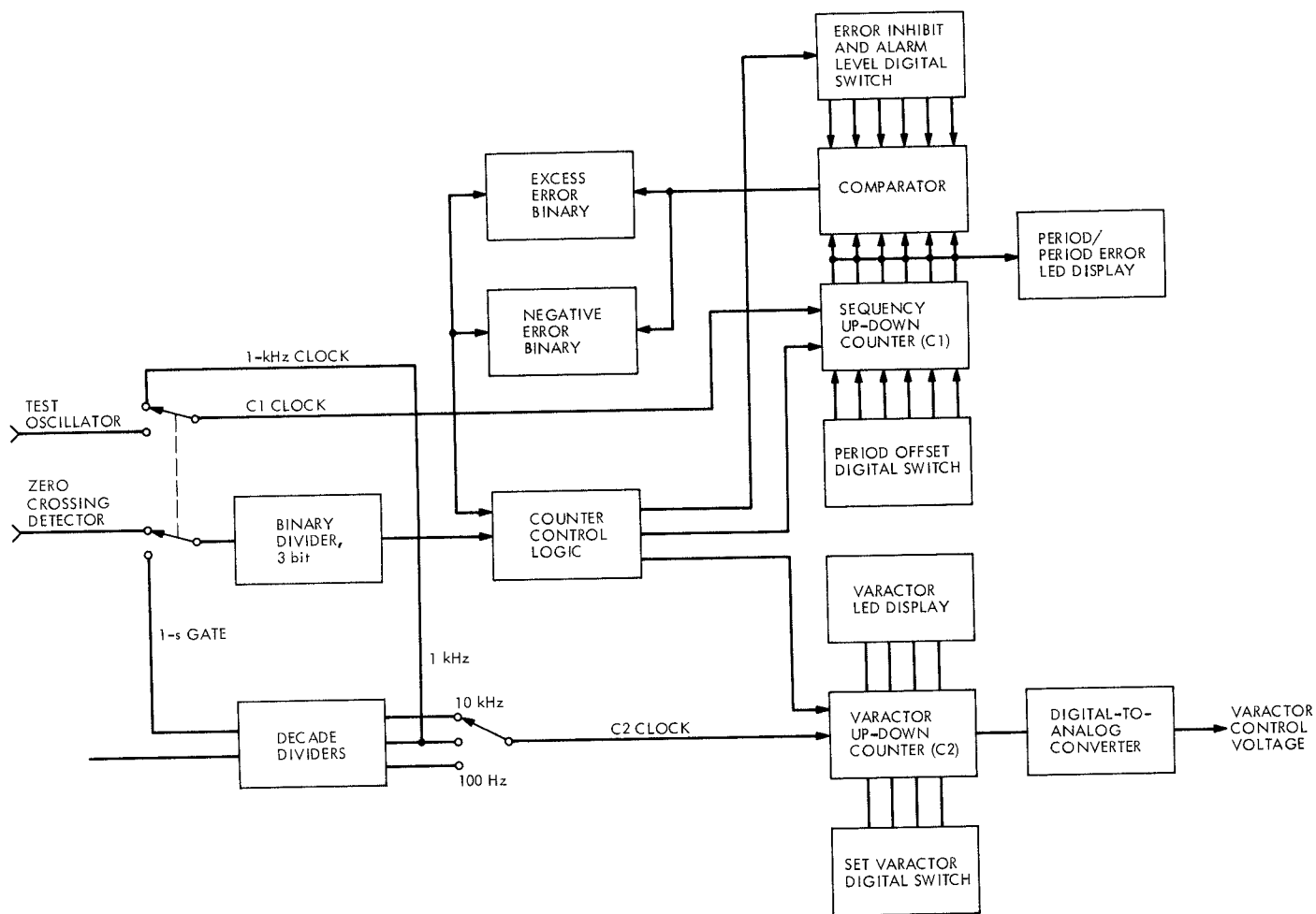


Fig. 3. Auto tuner control module block diagram